Miniaturized Top-Metalized 3D-printed Rectangular Dielectric Resonator Antenna

Francisco Javier Herraiz-Martínez[(1)], Mario Pérez-Escribano[(2)], Paris Sofokleous[(1)], Pablo Padilla[(3)], and Enrique Márquez-Segura[(2)]

[(1)] Institute for Research in Technology (IIT), Universidad Pontificia Comillas, 28015 Madrid, Spain (fjherraiz@comillas.edu)
[(2)] Telecommunication Research Institute (TELMA), Universidad de Málaga,
E.T.S. Ingeniería de Telecomunicación, 29010 Málaga, Spain
[(3)] Department of Signal Theory, Telematics and Communications,
Research Centre for Information and Communication Technologies (CITIC-UGR), University of Granada, Granada, Spain

***Abstract*—This paper introduces a novel top-metalized Dielectric Resonator Antenna (DRA). The inclusion of top metallization induces a modification in the boundary conditions, resulting in a frequency reduction in the fundamental mode of the DRA. A prototype is designed for the 2.45-GHz WiFi band with a –10-dB bandwidth from 2.40 to 2.51 GHz. The radiation maxima occur in the top and bottom directions, with a gain of 1.81 dBi at 2.45 GHz. The proposed DRA is specifically designed for manufacturing using commercially available materials and additive manufacturing techniques.**

I. Introduction

The current trend in electronic devices emphasizes their size reduction, as they are often intended for portability, pocket-sized use, or integration into various objects such as clothing or medical systems. Consequently, the miniaturization of antennas has garnered the attention of researchers in recent decades [1]. Dielectric Resonator Antennas (DRAs) offer several advantages, including reduced size, high radiation efficiency, and multiple excitation possibilities [2]. The authors have recently demonstrated the feasibility of employing additive manufacturing techniques to produce Dielectric Resonators (DRs) [3]. Additionally, in the literature, there are 3D-printed antennas made from conductive filaments [4]. Both techniques can be employed to develop fully 3D-printed DRAs.

This paper introduces a novel top-metalized DR antenna. The proposed design achieves significant size reduction compared to a conventional DRA with the same permittivity. The antenna is designed for manufacturing using commercially available materials and additive manufacturing techniques.

II. Antenna Analysis and Design

The proposed antenna is shown in Fig. 1. It consists of a rectangular DR. The DR is metalized in the upper and lower parts. Thus, the lower metallization acts as a ground plane, but the upper metallization changes the boundary condition compared to a conventional DRA. The antenna is fed by a vertical probe made from a coaxial SMA connector. The inner pin of the coaxial connector is inserted into the dielectric material, acting as a vertical probe, while the outer connector is welded to the ground plane. The position of the vertical probe (d_y, d_z) and its height inside the resonator (h) are used to get a good matching.

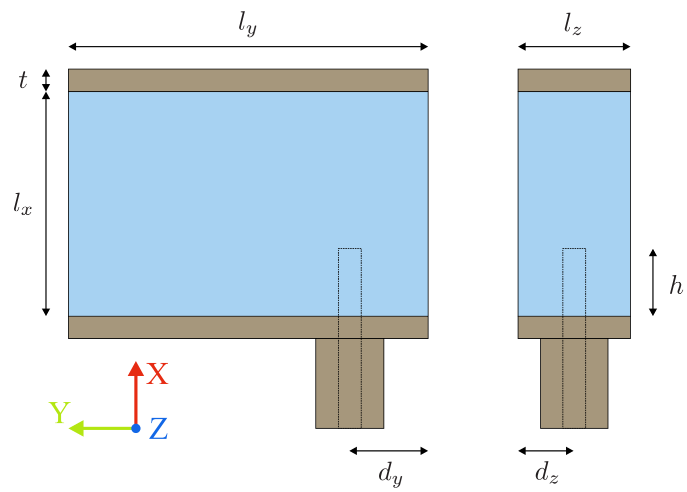

Fig. 1. Geometry of the proposed top-metalized DRA.

A. Modal Analysis

In the conventional DRA without top-metalization, the ground plane is considered a Perfect Electric Conductor (PEC), and the rest of the walls are Perfect Magnetic Conductors (PMC) [5]. Therefore, the boundary conditions can be expressed as

$$E_z(x=0, 0 \leq y \leq l_y, 0 \leq z \leq l_z) = 0, \tag{1a}$$
$$E_y(x=0, 0 \leq y \leq l_y, 0 \leq z \leq l_z) = 0, \tag{1b}$$
$$H_x(0 \leq x \leq l_x, y=0, 0 \leq z \leq l_z) = 0, \tag{1c}$$
$$H_x(0 \leq x \leq l_x, y=l_y, 0 \leq z \leq l_z) = 0, \tag{1d}$$
$$H_y(x=l_x, 0 \leq y \leq l_y, 0 \leq z \leq l_z) = 0. \tag{1e}$$

and the vector potential F_z^+ is

$$F_z^+ = A_{mn} \cos(\beta_x x) \sin(\beta_y y) e^{-j\beta_z z}, \tag{2}$$

where

$$\beta_x = \frac{(2m+1)\pi}{2l_x}, \tag{3a}$$
$$\beta_y = \frac{n\pi}{l_y}. \tag{3b}$$

TABLE I

MAIN DIMENSIONS OF THE PROPOSED ANTENNA PROTOTYPE

Parameter	l_x	l_y	l_z	d_z	d_y	t	h
Value (mm)	17	25.25	11.50	5.75	5	0.40	8

In this case, m can take values 0,1,2,3... whereas n can take values 1,2,3... The fundamental mode is TE_{01}, whose resonant frequency is calculated from

$$(f_c)_{mn} = \frac{c_0}{2\pi\sqrt{\varepsilon_r}}\sqrt{\beta_x^2 + \beta_y^2}. \tag{4}$$

On the other hand, in the proposed top-metalized DRA, the ground plane and the top metallization are considered PEC, whereas the other walls are still PMC. The boundary conditions are now

$$E_z(x = 0, 0 \le y \le l_y, 0 \le z \le l_z) = 0, \tag{5a}$$
$$E_z(x = l_x, 0 \le y \le l_y, 0 \le z \le l_z) = 0, \tag{5b}$$
$$E_y(x = 0, 0 \le y \le l_y, 0 \le z \le l_z) = 0, \tag{5c}$$
$$E_y(x = l_x, 0 \le y \le l_y, 0 \le z \le l_z) = 0, \tag{5d}$$
$$H_x(0 \le x \le l_x, y = 0, 0 \le z \le l_z) = 0, \tag{5e}$$
$$H_x(0 \le x \le l_x, y = l_y, 0 \le z \le l_z) = 0. \tag{5f}$$

Although the vector potential F_z^+ and β_y are given by the same expressions (see Eq. (2)), the value of β_x is now

$$\beta_x = \frac{m\pi}{l_x}. \tag{6}$$

where m can take again values 0,1,2,3 ...

This difference is because, in this case, the parallel walls of the x-axis have the same boundary condition. In contrast, in the previous case, the boundary conditions of that axis were different. The fundamental mode of the proposed antenna is TE_{01}, but its resonant frequency computed from (4) is smaller than in the case of the conventional antenna due to the change in β_x. This leads to the desired miniaturization of the electrical size of the DRA.

B. Antenna Design for WiFi Application

The antenna has been designed to work in the 2.45 GHz WiFi band. The proposed antenna dimensions are shown in Table I. The DR is implemented by 3D printing using a Zirconia-based commercial filament from Zetamix. This material is made of PLA with a 50% load of Zirconia ceramic. The authors have previously shown that using a conventional FDM printer without any postprocessing technique, this material can produce a DR with relative permittivity $\epsilon_r = 8.16$ and $\tan\delta = 0.0073$ [3]. The metallizations are 3D printed with Electrifi conductive material from Multi3D. An antenna prototype has been manufactured with a TUMaker Pro Dual printer.

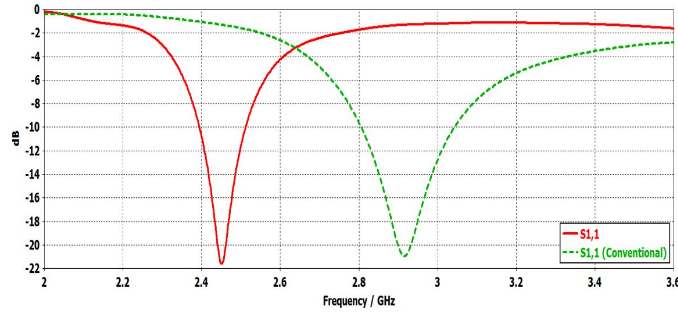

Fig. 2. Simulated reflection coefficient of the proposed (solid red) and conventional (dashed green) DRAs.

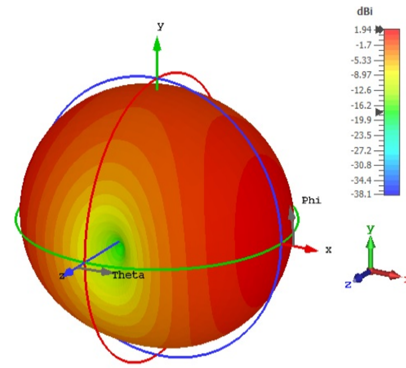

Fig. 3. Simulated radiation pattern of the proposed antenna.

III. RESULTS AND CONCLUSION

The conventional and the proposed DRAs have been simulated in CST Studio Suite by Simulia. Fig. 2 shows the reflection coefficient of both antennas. The proposed top-metalized DRA has a -10 dB bandwidth from 2.40 to 2.51 GHz, covering the desired WiFi band. The minimum of the reflection coefficient (-10 dB) is achieved at 2.45 GHz. On the other hand, the conventional antenna has the minimum S_{11} value at 2.92 GHz. Thus, an important electrical size reduction is achieved with the proposed design. Fig. 3 shows the simulated radiation pattern of the proposed antenna, where the maxima are located at the top and bottom directions (x-axis) while the minima are along the z-axis. The gain at 2.45 GHz is 1.81 dBi.

REFERENCES

[1] M. Fallahpour, and R. Zoughi, "Antenna miniaturization techniques: A review of topology-and material-based methods," in *IEEE Antennas and Propagation Magazine*, vol. 60, no. 1, pp. 38–50, 2017.

[2] M. W. McAllister, S. A. Long, and G. L. Conway, "Rectangular dielectric resonator antenna," in *Electronics Letters*, vol. 19, no. 6, pp. 218-219, March 17 1983.

[3] P. Sofokleous, E. Paz, and F. J. Herraiz-Martínez, "Design & manufacturing of dielectric resonators via material extrusion 3D printing using low-cost polymeric/ceramic filaments," in *Additive Manufacturing*, unpublished.

[4] F. Pizarro et al., "Parametric Study of 3D Additive Printing Parameters Using Conductive Filaments on Microwave Topologies," in *IEEE Access*, vol. 7, pp. 106814–106823, 2019.

[5] H. Yuet Yee, "Natural Resonant Frequencies of Microwave Dielectric Resonators (Correspondence)," in *IEEE Transactions on Microwave Theory and Techniques*, vol. 13, no. 2, pp. 256-256, Mar 1965.